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C_6F_5XeF, A Key Substrate in Xenon – Carbon Chemistry: Synthesis of Symmetric and Asymmetric Pentafluorophenylxenon(II) Derivatives**

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Salt-like compounds with a C–Xe bond in the cationic part $[RXe]^+$ have been known since 1989, where R represents an aryl,[1] alkenyl,[2] or alkynyl group[3]. In contrast $C_6F_5XeO_2CC_6F_5$,[4] C_6F_5XeCl and $[(C_6F_5Xe)_2Cl]^+$[5] contain weaker covalent C–Xe bonds (3c-4e bonds[6], asymmetric, hypervalent bonds with different distinct heteropolar components). The existence of the symmetric, hypervalent, molecular compound $Xe(CF_3)_2$[7] is extremely doubtful, and unambiguous proof of its constitution has not yet been provided.

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[**] This work was supported by the Deutsche Forschungsgemeinschaft and the Fonds der Chemische Industrie.

On the basis of high values of group electronegativity, for example, $Xe(C_6F_5)_2$ and $Xe(CN)_2$ should be favored for a new class of symmetric C-Xe-C molecules, since their C(1) atom is part of a polarizable π system and the strongly electron-withdrawing components make the C-ligand electron-poor.

Herein we present a new concept for the synthesis of covalent C_6F_5Xe-C and C_6F_5Xe-Y compounds, specific examples being $Xe(C_6F_5)_2$ and C_6F_5XeCN[8]. This concept is based on the new molecule C_6F_5XeF (**1**)[9] which is the decisive key substrate. The asymmetric hypervalent molecule **1** is formed in 70 % yield as the soluble product of the heterogeneous low-temperature reaction of $[C_6F_5Xe]^+$ salts with "naked" fluoride $[NMe_4]F$ in CH_2Cl_2 [Eq. (1)]. The alternative approach, the electrophilic substitution of E in C_6F_5-E with $[FXe]^+$ does not lead to **1**, because the oxidation potential of $[FXe]^+$ is too high even for fluoroaromatics.

$$[C_6F_5Xe][Y]_{(s)} + [NMe_4]F \xrightarrow[\text{slow}]{CH_2Cl_2,\ -78\,^\circ C} \underset{\mathbf{1}}{C_6F_5XeF} + [NMe_4][Y]\downarrow \qquad (1)$$

$Y = AsF_6, BF_4$

If the soluble source of fluoride in Equation (1) is used in a smaller than stoichiometric amount, multinuclear fluoro-bridged xenonium species result [Eq. (2)]:

$$2\,[C_6F_5Xe][AsF_6]_{(s)} + [NMe_4]F \xrightarrow[\text{slow}]{CH_2Cl_2,\ -78\,^\circ C} [(C_6F_5Xe)_2F][AsF_6]\downarrow + [NMe_4][AsF_6]\downarrow \qquad (2)$$

Ab initio calculations (comparison in the gas phase) show that the C–Xe distance in **1** is longer than in the $[C_6F_5Xe]^+$ ion and the Xe–F distance is greater than in XeF_2. The latter feature makes the F^- ion a good leaving group. The permanent dipole moment in **1** makes the successful attack of nucleophiles on the electrophilic Xe center easier. With $Cd(C_6F_5)_2$ as an aryl transfer reagent it is possible to introduce a second aryl group into **1** [Eq. (3)]:

$$\underset{\mathbf{1}}{2\,C_6F_5XeF} + Cd(C_6F_5)_2 \xrightarrow[\text{fast}]{CH_2Cl_2,\ -78\,^\circ C} \underset{\mathbf{2}}{2\,Xe(C_6F_5)_2} + CdF_2\downarrow \qquad (3)$$

The direct introduction of the C_6F_5 group into XeF_2 within the thermal-existence range of **2** is not successful with $Cd(C_6F_5)_2$, as the nucleophilicity of the aryl group (no permanent dipole moment) does not suffice for the substitution on XeF_2. The nucleophilicity of the aryl group in $Me_3SiC_6F_5$ in CH_2Cl_2 is not high enough for the successful F-C_6F_5 substitution in **1** [Eq. (4)] (see also ref. [10]):

$$C_6F_5XeF + Me_3SiC_6F_5 \xrightarrow[CH_2Cl_2,\ <10\,h]{-70\rightarrow-40\,^\circ C} \mathbf{2} + Me_3SiF \qquad (4)$$

However, with Me_3SiCN the CN group can be introduced successfully into **1** [Eq. (5)]:

$$\underset{\mathbf{1}}{C_6F_5XeF} + Me_3SiCN \xrightarrow[\text{spontaneous}]{CH_2Cl_2,\ -78\,^\circ C} \underset{\mathbf{3}}{C_6F_5XeCN} + Me_3SiF \qquad (5)$$

We attribute the different reactivities of $Me_3SiC_6F_5$ and Me_3SiCN more to differences in Lewis acidity than to steric effects.

  1433-7851/00/3924-4591 $ 17.50+.50/0

The symmetric C-Xe-C molecule **2** as well as the asymmetric molecules **1** and **3** are soluble in polar, weak-coordinating solvents, such as CH_2Cl_2. When dissolved in basic, strongly coordinating MeCN compound **1** shows no heterolysis to the $[C_6F_5Xe]^+$ and F^- ions. Compounds **1**–**3** are unstable at room temperature and even at $-78\,^\circ C$ their CH_2Cl_2 solutions decompose within a few weeks. The products of decomposition point to homolytic breakage of bonds followed by radical recombinations and radical attacks on the solvent.

Both electronegative aryl groups in **2** show a relatively high anionic character. In the superacidic solvent aHF (anhydrous HF) one of the aryl groups can be quantitatively split off through electrophilic attack forming equimolar amounts of $[C_6F_5Xe]^+$ and C_6F_5H [Eq. (6)]:

$$Xe(C_6F_5)_2 + (n+1)\,HF \xrightarrow{-40\,^\circ C} [C_6F_5Xe][F(HF)_n] + C_6F_5H \quad (6)$$

In the presence of I_2 compound **2** behaves as an arylating agent [Eq. (7)]:

$$Xe(C_6F_5)_2 + I_2 \xrightarrow{-78\,^\circ C,\ CH_2Cl_2} 2\,C_6F_5I + Xe^0 \quad (7)$$

The reactions of **3** with I_2 or HF proceed in a more complex manner because of the inequivalent C–Xe bonds. The reaction of the C_6F_5 group in **3** was monitored by ^{19}F NMR spectroscopy and the products C_6F_5I, C_6F_5H, and C_6F_5CN (5:3:1) or $[C_6F_5Xe]^+$, C_6F_5H, and C_6F_5CN (4:1:3) were detected. As a result of its good fluoride donor ability **1** reacts even with weak Lewis acids such as SiF_4 or $C_6F_5BF_2$ [Eqs. (8), (9)]:

$$C_6F_5XeF + SiF_4 \longrightarrow [C_6F_5Xe][SiF_5] \quad (8)$$

$$C_6F_5XeF + C_6F_5BF_2 \longrightarrow [C_6F_5Xe][C_6F_5BF_3] \quad (9)$$

The constitution of **1**–**3** was confirmed by heteronuclear NMR spectroscopy (^{19}F, ^{129}Xe, ^{13}C, ^{15}N; Table 1) in CH_2Cl_2 solutions. The coupling constants were determined in some cases by ^{19}F- or ^{129}Xe-decoupling experiments. The ^{129}Xe NMR spectrum of **1** shows the large $^1J_{Xe,F}$ (doublet, 4014 Hz) and the smaller $^3J_{Xe,o\text{-}F}$ coupling (triplet, 82 Hz) that confirm unambiguously the constitution of **1**. In the ^{129}Xe NMR spectrum of **2** the resonance signal at $\delta = -4152$ (the lowest frequency of a Xe^{II} species!) appears as a not fully resolved multiplet. The accompanying *o*-F signal at $\delta = -133.05$ shows ^{129}Xe satellites of appropriate intensity. The $^3J_{F,Xe}$ coupling is determined (by using selective *m*-F decoupling) to be 43 Hz. The ^{129}Xe NMR spectrum of C_6F_5XeCN shows a triplet ($^3J_{Xe,F} = 86$ Hz) at $\delta = -3883.2$. In the labeled compound $C_6F_5Xe^{13}CN$ (Figure 1) an additional doublet ($^1J_{Xe,C} = 1060$ Hz) is observed. In the labeled compound $C_6F_5XeC^{15}N$ the ^{129}Xe NMR resonance signal (^{19}F decoupled) appears as a doublet ($^2J_{Xe,N} = 21$ Hz).

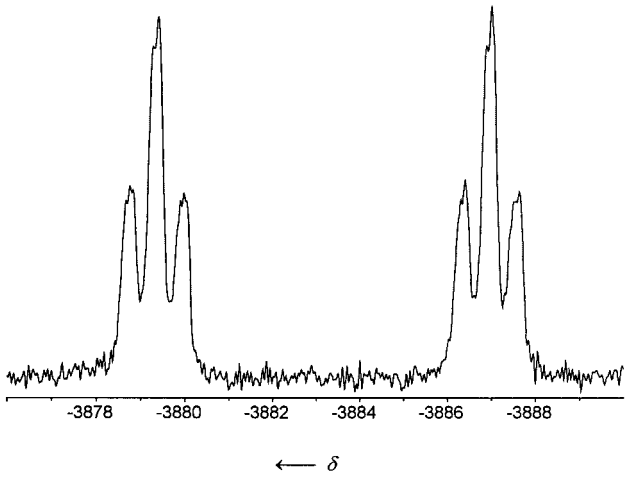

Figure 1. ^{129}Xe NMR spectrum of $C_6F_5Xe^{13}CN$ in CD_2Cl_2 at $-78\,^\circ C$.

Table 1. NMR spectroscopic characterization of compounds **1**–**3**[a].

^{19}F NMR		δ(*o*-F)	δ(*p*-F)	δ(*m*-F)	δ(Xe-F)	$^3J_{p\text{-}F,F}$	$^3J_{F,Xe}$	$^4J_{F,Xe\text{-}F}$	$^1J_{F,Xe}$
RXeF	**1**	−129.35	−146.87	−156.49	−3.50[b]	20	81[c]	19[c]	4010
RXeR	**2**	−133.05	−154.14	−159.04		21	43[c]		
RXeCN	**3**	−131.54	−147.50	−156.39		21	87		
$^{13}C\{^{19}F\}$ NMR		δC(1)	δC(2.6)	δC(3.5)	δC(4)	$^1J_{C,Xe}$	$^2J_{C(1),o\text{-}F}$	$^2J_{C,Xe\text{-}F}$	$^3J_{C,Xe\text{-}F}$
RXeF	**1**	86.35	143.90	137.14	143.09	111[d]	28	115[d]	ca. 6[c]
RXeR	**2**	122.59	143.01	136.31	140.64				
RXeCN	**3**[e]	103.07	143.11	137.10	142.82	66			
^{129}Xe		Xe				$^3J_{Xe,F}$	$^1J_{Xe,F}$		
RXeF	**1**	−3789.2				82	4014		
RXeR	**2**	−4152[f]							
RXeCN	**3**	−3883.2				86			
selected δ and *J*-values of the labeled compound **3**:									
^{13}C		δCN				$^1J_{CN,Xe}$	$^2J_{CN,C(1)}$		
$RXe^{13}CN$		125.68				1060	142		
^{15}N		δCN				$^2J_{N,Xe}$			
$RXeC^{15}N$		123.7				22			

[a] R = C_6F_5. The NMR measurements proceeded in FEP sample tube liners (FEP = tetrafluoromethylene hexafluoropropylene copolymer) in CD_2Cl_2 at $-78\,^\circ C$ with a Bruker AVANCE-DRX-500 spectrometer. The absolute values of the coupling constants *J* in Hz. The ^{19}F, ^{129}Xe, ^{13}C, and ^{15}N chemical shift values are relative to the standards C_6F_6 ($\delta(CCl_3F) = -162.9$ ppm), $XeOF_4$ (24 °C), TMS, and CD_3NO_2 (24 °C), respectively, at the corresponding measurement temperature. [b] s, br, $\tau_{1/2}$ becomes smaller after addition of F^- ions.[11] [c] From ^{19}F-decoupling experiments. [d] From insensitive nuclei enhancement by polarization transfer (INEPT) experiments. [e] $\delta(CN) = 125.22$. [f] m, $\tau_{1/2} \approx 150$ Hz.

  1433-7851/00/3924-4592 $ 17.50+.50/0 *Angew. Chem. Int. Ed.* **2000**, *39*, No. 24

Table 2. Calculated (Gaussian 94, RHF, LANL2DZ) geometric parameters and charges (Mulliken) of C_6F_5Xe-Z molecules[a].

C_6F_5Xe-Z	Molecule	Sym.	Selected geometric parameters[b]			Selected Mulliken charges			
			C(1)-Xe	Xe-Z	C(2)-C(1)-C(6)	Xe	C_6F_5	C(1)	Z
C_6F_5Xe-F	**1**	C_s	2.20	2.13	117.7	1.148	−0.415	−1.001	−0.733
C_6F_5Xe-C_6F_5	**2**	C_1	2.34	2.34	117.4	0.980	−0.490	−0.687	−0.490
C_6F_5Xe-CN	**3**	C_s	2.24	2.38	118.1	0.967	−0.403	−0.853	−0.564[c]
for comparison see ref [12]									
$C_6F_5Xe\cdots$F-AsF_5		$\approx C_s$	2.12	2.56	121.3	1.083	−0.134	−1.032	−0.948
$[C_6F_5Xe]^+$		C_s	2.16	–	122.7	0.886	0.114	−0.870	–
FXeF		$D_{\infty h}$	–	2.03	–	1.306	–	–	−0.653

[a] Z = second ligand bound to Xe^{II}; [b] in [Å] or [°], repectively; [c] Mulliken charges of C in the CN ligand: −0.466.

The results of ab initio calculations for **1**–**3** show the following sequence of C-Xe distances: **2** > **3** > **1**, thus opposite to the sequence of Mulliken charges of the ligand Z in C_6F_5XeZ (Table 2). The comparison of data for **1** and $C_6F_5Xe\cdots FAsF_5$ [12] elucidates clearly the change when going from the asymmetric hypervalent C-Xe-F bond to a significant C-Xe $\cdots$ F contact: the negative charge on Z gets closer to −1 whereas the negative charge of the C_6F_5 group decreases significantly. The high anionic character of the C_6F_5 group in **1**–**3** agrees with the observed reactivities towards electrophiles and explains the lower-frequency chemical shifts of the *p*-F atom compared to $[C_6F_5Xe]^+$.

Experimental Section

1: A cold solution of $[NMe_4]F$ (25 mg, 0.27 mmol) in CH_2Cl_2 (1 mL) was added to a suspension of $[C_6F_5Xe][AsF_6]$ (131 mg, 0.27 mmol) in CH_2Cl_2 (1.5 mL) at −78 °C in an 8 mm FEP trap. The suspension was stirred over 2 days at −78 °C until all the fluoride was consumed. The mother liquor was separated from solid $[NMe_4][AsF_6]$ and the quantity of **1** was determined (^{19}F NMR): 0.19 mmol, 70%. The other reactions were usually performed directly with the cold solutions of **1**. By evaporating CH_2Cl_2 at 10^{-2} hPa/ ≤ −55 °C and later drying at ≤ −40 °C **1** was obtained as a colorless solid, which after warming to 20 °C decomposed totally within 4 h. In CH_2Cl_2 solution noticeable decomposition proceeded above −30 °C with the formation of C_6F_5H and traces of C_6F_5Cl.

2: A cold solution of $Cd(C_6F_5)_2$ (17 mg, 0.04 mmol) in CH_2Cl_2 (0.5 mL) was added to a solution of **1** (0.08 mmol) in CH_2Cl_2 (1.5 mL) at −78 °C. After 5 min of stirring CdF_2 precipitated. The reaction was complete (^{19}F NMR) after further 10 min. The mother liquor was collected. In addition to **2** (0.06 mmol, 75%) the solution contained C_6F_5H (4 μmol) and $(C_6F_5)_2$ (2 μmol). The isolation of solid **2** was achieved as described for **1**. Solid **2** decomposes completely at room temperature within 1 h and in CH_2Cl_2 solution at −40 °C within 9 h [C_6F_5H:$(C_6F_5)_2$ = 1:0.1].

3: A cold solution of Me_3SiCN (14 μL, 0.10 mmol; or the labeled ^{13}CN and $C^{15}N$ derivatives) in CH_2Cl_2 (0.5 mL) was added to a solution of **1** (0.10 mmol) and CH_2Cl_2 (1.5 mL) at −78 °C and stirred. After 5 min the reaction was complete (^{19}F NMR: quantitative reaction) giving a 1:1 mixture of **3** and Me_3SiF. CH_2Cl_2 and Me_3SiF were distilled at ≤ −55 °C/ 10^{-2} hPa and the white solid product was dried at ≤ −40 °C/10^{-2} hPa. The solid spontaneously decomposed during the rapid warming to room temperature. CH_2Cl_2 solutions of **3** decomposed completely at −40 °C within 2 h with the formation of C_6F_5CN and C_6F_5H (4:1).

Checking the purity of the cold solid products after dissolution in CH_2Cl_2 at −78 °C showed in the case of **1** and **2** degrees of decomposition of up to 10% and for the thermally more sensitive product **3** up to 30%.

Received: August 18, 2000 [Z15656]

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An Enantiospecific Synthesis of the Potent Immunosuppressant FR901483**

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Bond formations induced by phenol oxidations have a rich history in organic chemistry. The influential two-step synthesis of usnic acid by Sir Derek Barton and co-workers[1] followed a set of simple rules that provided guidelines for rationalizing the course of oxidative phenolic radical couplings occurring in the biogeneses of a number of natural products.[2] We were

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[**] Dr. G. Scheffler and H. Seike contributed equally to this work. We thank Dr. L. B. Pasternack and Dr. D. H. Huang for NMR spectroscopic assistance, and Dr. G. Siuzdak for mass spectrometric assistance. We also thank Dr. S. Takase and Dr. H. Setoi from the Fujisawa Pharmaceutical Co. for physical data for FR901483. This work was generously supported by The Skaggs Institute for Chemical Biology, a grant from the Merck Research Laboratories, a Beckman Young Investigator Award to E.J.S., and a predoctoral fellowship from the Heiwa Nakajima Foundation to H.S.